University of Pittsburgh

Algorithms and Data Structures 2
CS 1501

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(Slides are adapted from Dr. Ramirez's and Dr. Farnan's CS1501 slides.)

Announcements

- Upcoming deadlines:
  - Homework 3 is due on 2/7
  - Lab 2 is due on 2/4

Previous lecture …

- BinaryNode
- BinaryTree

CourseMIRROR Reflections

This Lecture

- Binary Search Tree
  - How to add and delete
- Runtime of BST operations
  - Find, add, delete
- Red-Black BST (Balanced BST)
  - definition and basic operations

Let's build a Binary Search Tree

- Work in groups of 2-3 students
- Add the following integers to a Binary Search Tree in **the following order**:

10, 8, 17, 7, 5, 20, 15, 16, 4

Reflect on the steps that you followed

- How did you add 4 to the tree?
- What steps did you follow?

10, 8, 17, 7, 5, 20, 15, 16, 4

How to add?

- How to add a data item *entry* into a BST rooted at *root?*
- What if root.data.compareTo(entry) == 0?
- What if root.data.compareTo(entry) < 0?
  - Move left or right?
  - What if no child?
  - What if there is a child?
- What if root.data.compareTo(entry) > 0?
  - Move left or right?
  - What if no child?
  - What if there is a child?
- What if I tell you that you have a friend who can add into a BST.
  - How can you use the help of that friend?

Let's see the code for adding into a BST

- Available online at:
  - https://cs1501-2224.github.io/handouts/CodeHandouts/TreeADT/Slides/#/7/0/0
  - The slides are under the CodeHandouts/TreeADT/slides folder in the handout repository
  - https://github.com/cs1501-2224/handouts

Let's build a Binary Search Tree

- Work in groups of 2-3 students
- Add the following integers to a Binary Search Tree in **the following order**:

4, 5, 7, 8, 10, 8, 15, 16, 17, 20

Reflect on the steps that you followed

- How many comparisons did you have to make to add 20?

4, 5, 7, 8, 10, 8, 15, 16, 17, 20

Run-time of add (and find by the way)

- # comparisons = height of the tree (in the worst case)
- Run-time is Theta(tree height)
- On average tree height is Theta(log n)
  - n is the number of data items

Let's switch to delete!

- Work in groups of 2-3 students
- In the Binary Search Tree that you built out of **the following order**:

10, 8, 17, 7, 5, 20, 15, 16, 4

- How would you delete 4?
- How would you delete 5?
- How would you delete 10?

Let's build a Binary Search Tree

- Work in groups of 2-3 students
- In the Binary Search Tree that you built out of **the following order**:

10, 8, 17, 7, 5, 20, 15, 16, 4

- How would you delete 4?
- How would you delete 5?
- How would you delete 10?

Let's see the code for deleting from a BST

- Available online at:
  - https://cs1501-2224.github.io/handouts/CodeHandouts/TreeADT/Slides/#/7/0/0
  - The slides are under the CodeHandouts/TreeADT/slides folder in the handout repository
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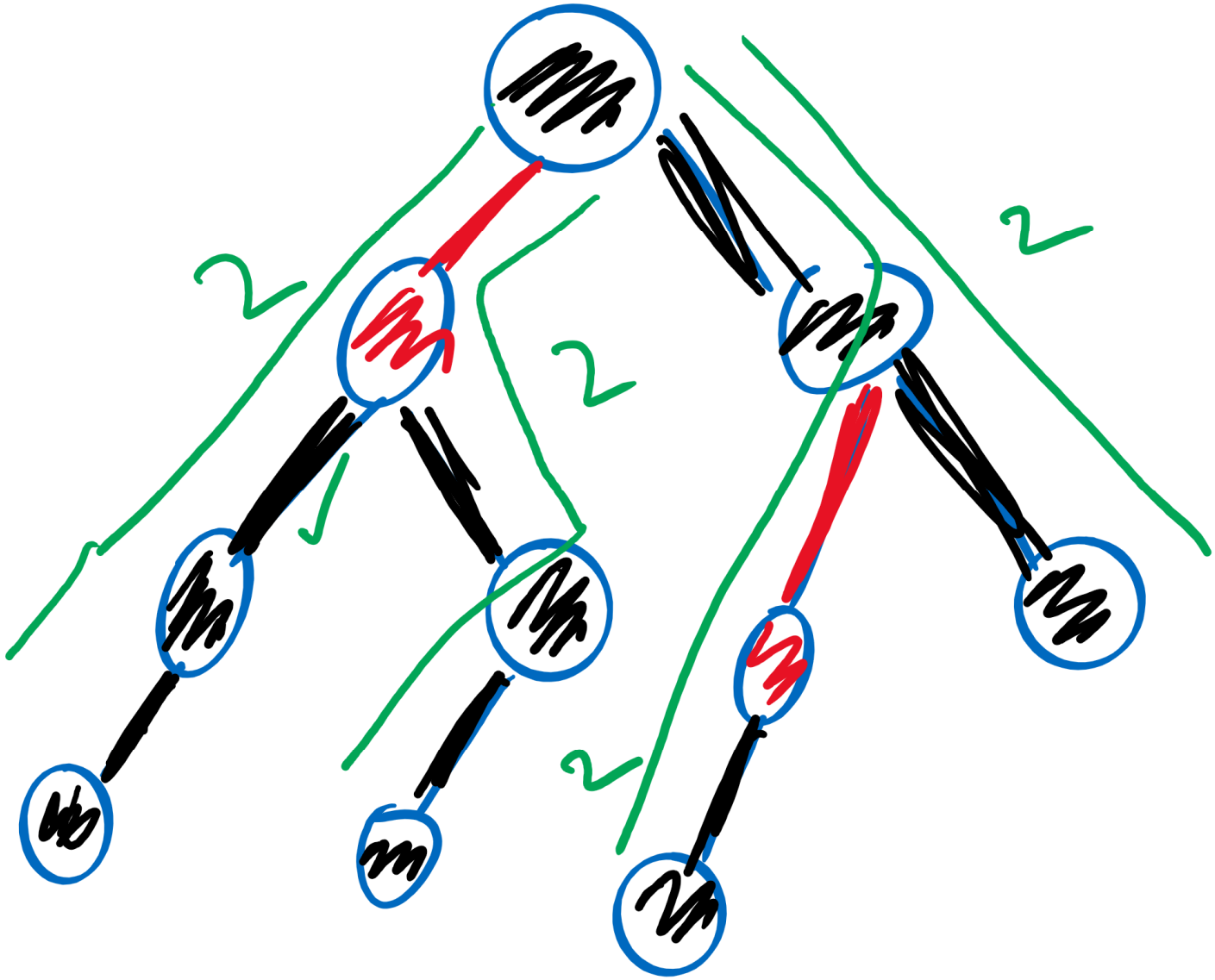
Red-Black BST

- Definition
  - two colors for links (nodes)
  - red links are always to the left children
  - at most one red-link per node
  - all black-link paths are the same
  - root node is always black
  - ***Why?***
    - ***maximum height = 2*log n !!***
- Basic operations
  - rotate left
  - rotate right
  - flip color
  - ***preserve the properties of the red-black BST!***

Red-black BST example



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